Capacity Evaluation and Modal Analysis of Lubricating Oil Sump of V-10 Diesel Engine

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Abstract—*Generally a lubricating oil sump is used to lubricate all the moving components in any IC engine. A wet sump design for engines uses the crankcase as a built-in reservoir for oil. In general, oil sump is subjected to engine excitation frequencies (i.e. running frequencies and firing frequencies) which may cause resonance if it coincides with natural frequencies of the oil sump. This resonance may result into severe damage. Hence oil sump will be designed in such a way that resonance frequency range must be avoided. In this paper, oil sump is designed to avoid failure due to excitation frequencies and leakage. Mainly this paper will focus on evaluation of oil sump capacity and modal analysis of same lubricating oil sump of V-10 diesel engine. Sump also affects NVH characteristics of engine. Some empirical relations and design formulae are used while calculating the exact oil sump capacity. With the help of crankcase layout, its CAD model is generated. Also modal analysis of oil sump is done using ANSYS to determine the vibration characteristics of sump. The results show that the range of natural frequency is avoided marginally and the total deformation is within the range.*

Keywords:modal analysis, natural frequency, mode shapes, oil sump.

I. INTRODUCTION

As human heart supplies blood to various parts of body, with same analogy an oil pump is a heart of lubricating oil system which supplies lubricating oil to all the moving parts of the engine. In most engines, which use a wet sump system, the oil is collected in a oil pan with adequate capacity at the base of the engine. Such oil pan is also known as the 'oil sump' where oil is pumped to the bearings and other interfaces by the oil pump, internal to the engine. Since the sump is internal, there is no need for hoses or tubes connecting the engine to an external sump which may leak. An internal oil pump is generally more difficult to replace, but that is dependent on the engine design. To design a proper oil sump for any engine, firstly it is essential to determine the exact oil sump capacity. Oil capacity depends upon necessary oil requirements at various lubricating interfaces. Basic thumb rules and design formulae are applied to find out the oil capacity and oil flow rate into the engine. For a particular flow rate, lubricating oil pump capacity is determined which will give exact oil sump capacity by using few empirical formulae. This oil sump capacity will give the volume of oil required at each instance for proper functioning of engine. This oil need to be supplied continuously at some specific interval with constant oil flow rate. After analysis and evaluation of oil requirement at each interfaces, the total oil sump capacity will be determined. Now, depending upon crankcase outline and the oil volume obtained by calculations we will get shape and size of sump.

II. ENGINE SPECIFICATIONS

1) Type : Four Stroke Diesel Engine
2) Configuration : V-10 Cylinder
3) Cylinder Displacement : 2 litres/Cylinder
4) Rating : 500 kVA @ 1500 rpm
5) Running Frequency : 25Hz
6) Firing Frequency : 125 Hz
7) Application : Power Generation (GENSET)

III. EXACT OIL CAPACITY CALCULATIONS

- Calculate necessary oil requirement at various lubricating interfaces (such as crank pin, main journal, rocker shaft, piston pin, cam bush, cam tappets, turbochargers, push rod, intermediate gear support, FIP tappets, piston cooling nozzle)
- Calculate total lubricating oil quantity for all interfaces
- Using design formulae and basic thumb rule, the exact flow rate is determined
- Considering all observable losses, the oil sump capacity is evaluated

A. *Empirical Relations Used For Calculations:*

Let, d = diameter
c = radial clearance

- Clearance area = π*d*c
- Flow rate evaluation –
  There are two basic thumb rules used to evaluate flow rate as:

Rule 1: –
  Q = 7.5 * clearance area (lph)
Rule 2: –
  Q = 0.036 * (diameter)^2 (lph)

B. *Formulae:*

1. Clearance = $\frac{0.13*d}{100}$
2. Clearance Area = π*d*c
3. Flow Rate (q_1) = 7.5*Clearance Area
4. Flow Rate (q_2) = 0.036*d^2
5. Total Flow Rate = Flow Rate*Number of Parts

C. Calculations :

Parts	Qty	Shaft Diameter	Clearance	Clearance Area	Total Flow (by Rule 1)	Total Flow (by Rule 2)	
		mm	mm	mm^2	lph	lph	
Crank Pin	10	96	0.1248	37.63	2822.909	3317.76	
Main Journal	6	110	0.143	49.41	2223.776	2613.6	
Rocker Shaft	20	25	0.0325	2.55	382.8816	450	
Piston Pin	10	55	0.0715	12.35	926.5735	1089	
Cam Bush	6	72	0.0936	21.17	952.732	1119.744	
Cam Tappets	20	32	0.0416	4.18	627.3132	737.28	
Turbo chargers	2			0	800	800	
Push Rod	20			0	200	200	
Intermediate Gear Support	1	60	0.078	14.70	110.2699	129.6	
FIP Tappets	10	32	0.0416	4.18	313.6566	368.64	
Piston Cooling Nozzle	10	Flow for non gallery cooled piston = 8 lit/kWhr			4904	4904	
					14264.11	15729.62	Total
					237.7352	262.1604	lpm
				(+) 10 % losses	262	288	lpm
					550		
					275		lpm
Minimum Oil Sump Capacity		Circulation of Entire Oil Volume 6 Times Through Pump				45.82	litre

D. CAD Model:

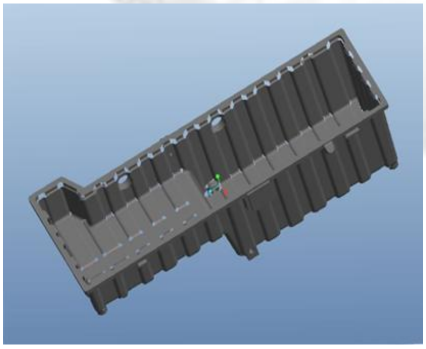

Fig. 1**:** Lubricating Oil Sump (Pro-E Model)

Consideringabove oil sump capacity, a CAD model is developed with the help of Pro-E. Shape and size of sump depends on crankcase layout as shown in Fig. 1. Material assigned for manufacturing is Aluminium. Along with that suction tube diameter, delivery tube diameter and drill gallery diameter is evaluated. As we know flow rate as 0.004582 m^3/s, assuming mechanical efficiency as 0.85 and pressure as 7MPa, power rating of pump is estimated as 3.77 kW.

IV. WHAT IS MODAL ANALYSIS?

Modal analysis is the process of determining the inherent dynamic characteristics of a system in the forms of natural frequencies, damping factors and mode shapes, and using them to formulate a mathematical model for its dynamic behavior. The formulated mathematical model referred as the modal model of the system. The dynamics of a structure are physically decomposed by frequency and position. This is clearly evidenced by the analytical solution of partial differential equations of continuous systems such as beams and strings. Modal analysis is based upon the fact that the vibration response of a linear-invariant dynamic system can be expressed as the linear combination of a set simple harmonic motions called the natural modes of vibration. This concept is akin to the use of a Fourier combination of sine and cosine waves to represent a complicated waveform. The natural modes of vibration are inherent to a dynamic system and are determined completely by its physical properties (mass, stiffness and damping) and their distributions. Each mode is described in terms of its modal parameters: natural frequency, the modal damping factor and characteristic displacement pattern, namely mode shape. The mode shape may be real or complex. Each corresponds to a natural frequency. The degree of participation of each natural mode in the overall vibration is determined by properties of the excitation source and the mode shapes of the system. Modal analysis embraces both theoretical and experimental techniques. The theoretical modal analysis anchors on a physical model of a dynamic system comprising its mass, stiffness and damping properties. These properties may be given in forms of partial differential equations. On the other hand, the rapid development has given rise to major advances in the experimental realm of the analysis, which is known as modal testing. It is an experimental technique used to derive the modal model of a linear time-invariant vibrating system. This technique establishes the relationship between the vibration response at one location and excitation at the same or another location as a function of excitation frequency. This relationship is known as frequency response function (FRF).

A. Modal Analysis of Lubricating Oil Sump

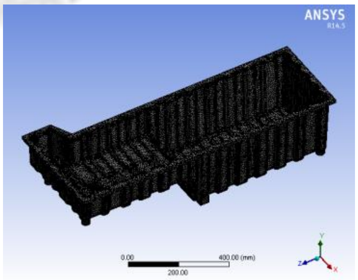

Fig. 2: Mesh Model (Mesh Size: 5mm)

In this paper, modal analysis of oil sump is carried out with the help of ANSYS. Natural frequencies obtained through this analysis show that they are marginally greater than the engine excitation frequencies. From the obtained results, it is clear that resonance is avoided. First 5 mode shapes along with natural frequency are shown in the figures below.

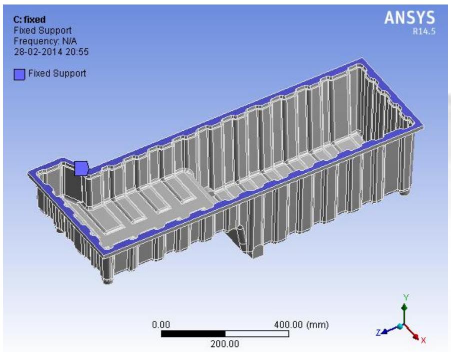

Fig. 3: Modal Model with boundary condition

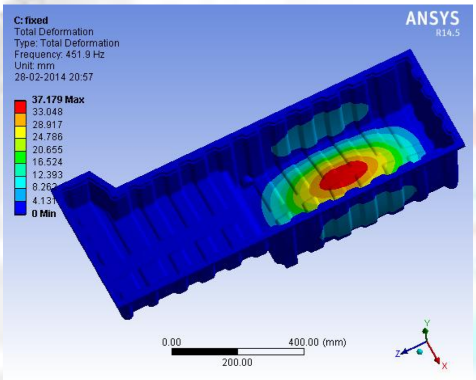

Fig.5: Mode 2 (Frequency = 498.35 Hz)

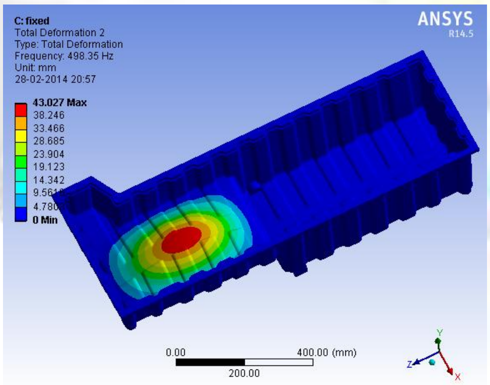

Fig. 4: Mode 1 (Frequency = 451.9 Hz)

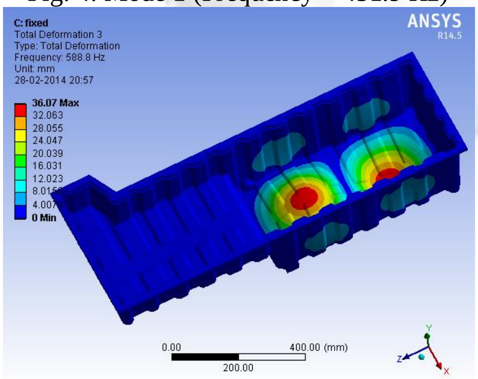

Fig. 6: Mode 3 (Frequency = 588.8 Hz)

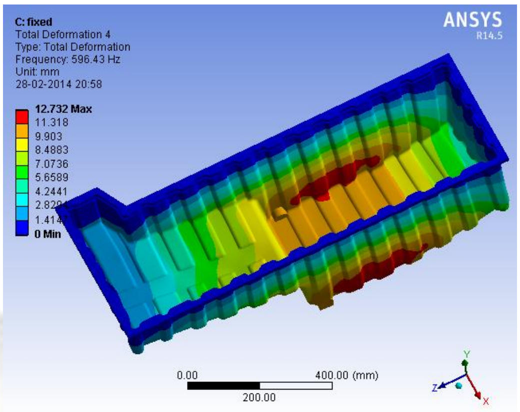

Fig.7: Mode 4 (Frequency = 596.43 Hz)

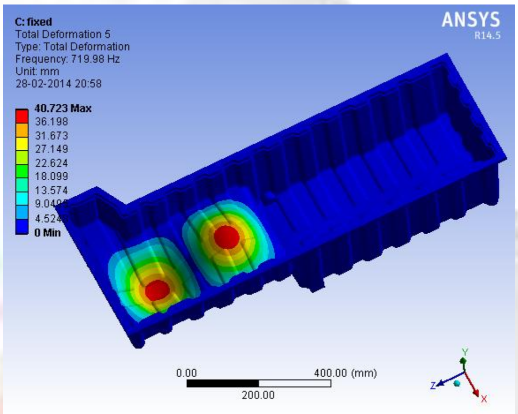

Fig. 8: Mode 5 (Frequency = 719.98 Hz)

V. CONCLUSION

In the presented study, exact oil sump capacity and its natural frequency is determined. The above study shows that the natural frequency of the oil sump which is far away from the running frequency and firing frequency of the engine. The running frequency and firing frequency are 25 Hz and 125 Hz respectively for V-10 diesel engine considered here and natural frequency of first mode of vibration is 451.9 Hz. The natural frequency gets increased as we proceed to next modes of vibration. So from the detailed analysis it is clear that, the excitation frequencies and natural frequencies are far apart from each other's. Hence resonance is avoided.

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